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Standardized Procedures for Planting Vegetation on Completed Sanitary Landfills

Rutgers - The State Univ., New Brunswick, NJ

Prepared for

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and is a most vital communications link between the researcher and the user community.

The standard operations manual has been prepared to disseminate information on vegetating completed sanitary landfills. Such information is especially needed as more completed landfills are being developed into parks, golf courses, nature areas, and other multiple-use facilities.

Francis T. Mayo
Director
Municipal Environmental Research Laboratory

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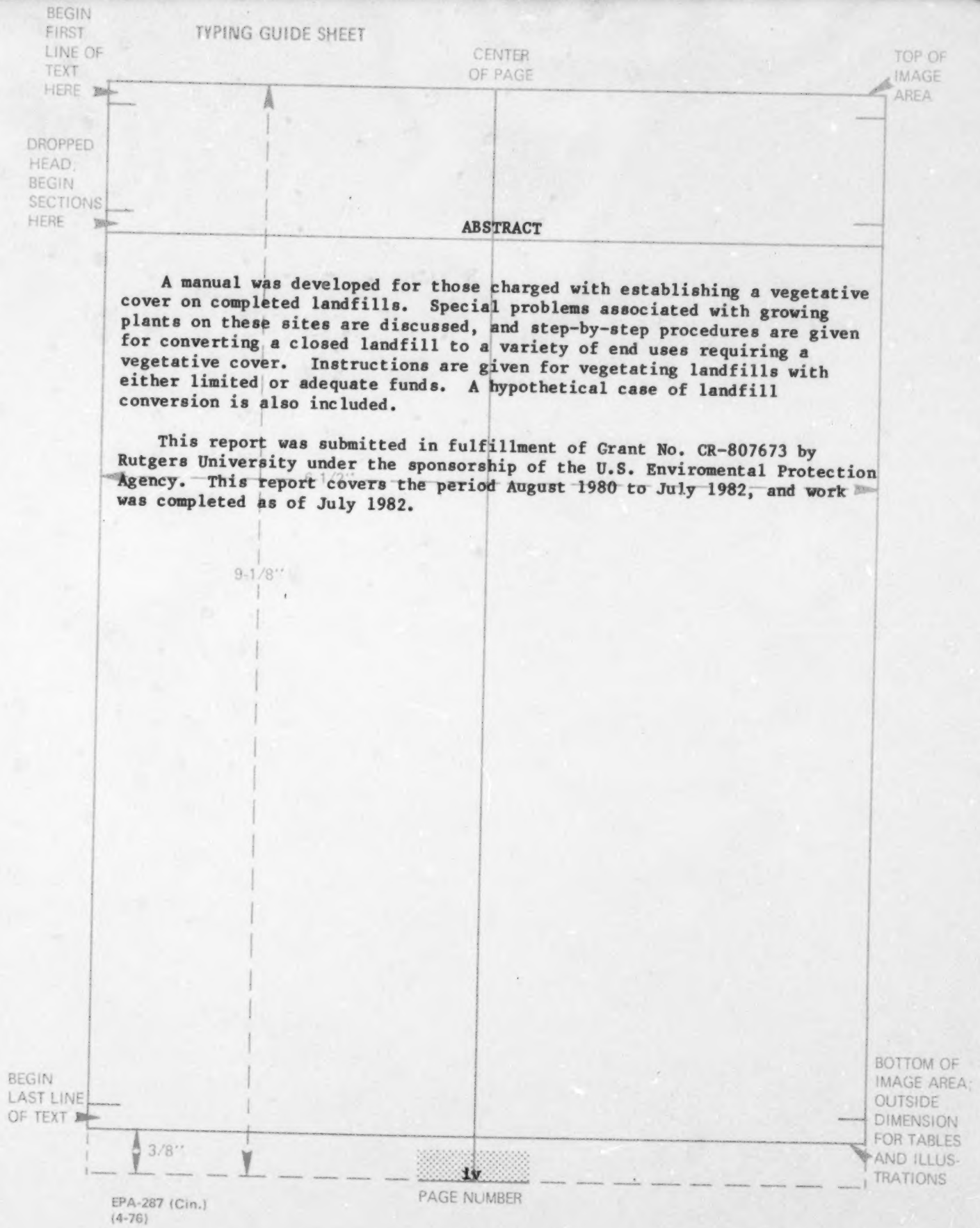
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A manual was developed for those charged with establishing a vegetative cover on completed landfills. Special problems associated with growing plants on these sites are discussed, and step-by-step procedures are given for converting a closed landfill to a variety of end uses requiring a vegetative cover. Instructions are given for vegetating landfills with either limited or adequate funds. A hypothetical case of landfill conversion is also included.
This report was submitted in fulfillment of Grant No. CR-807673 by Rutgers University under the sponsorship of the U.S. Enviromental Protection Agency. This report covers the period August 1980 to July 1982, and work was completed as of July 1982.
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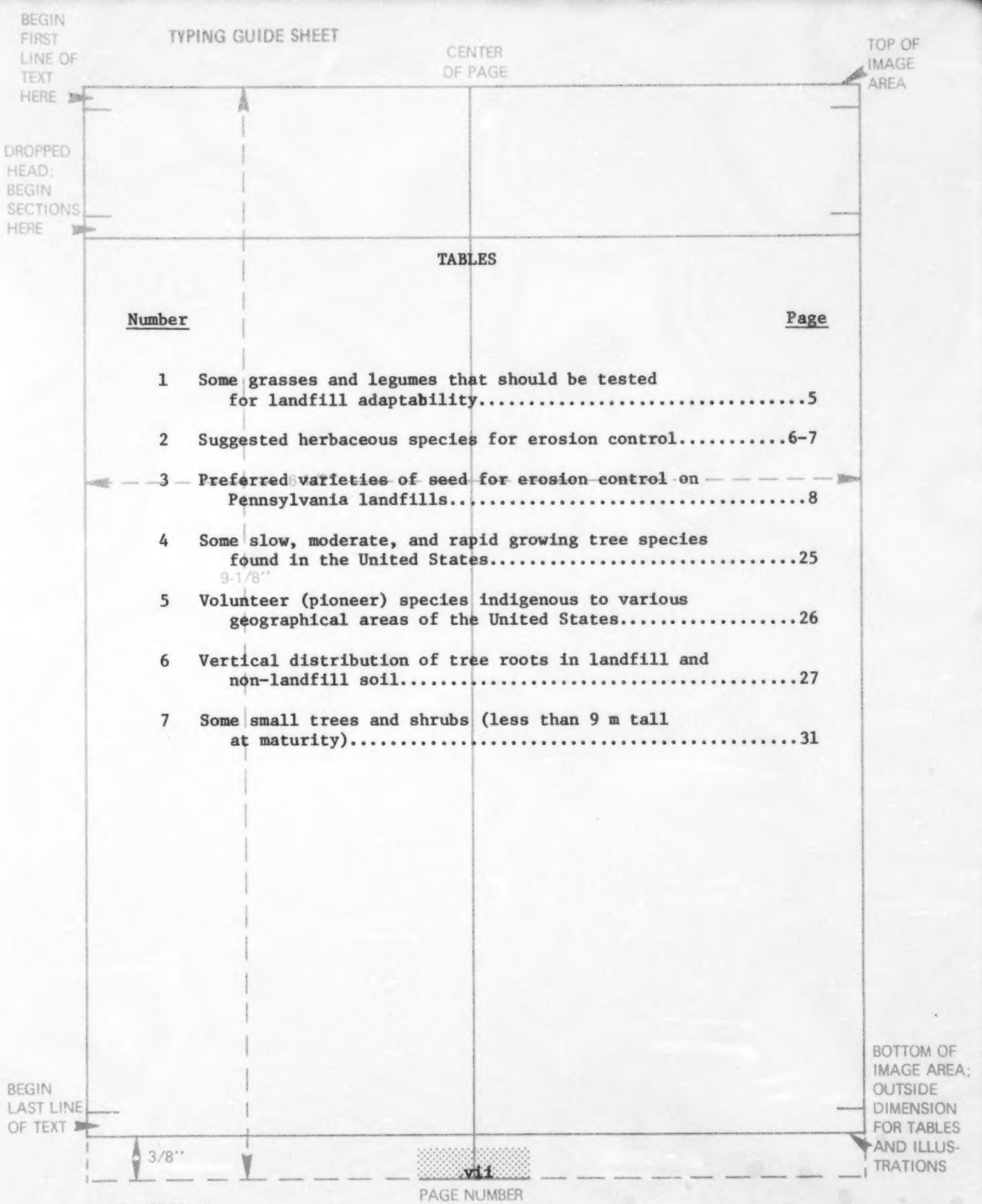
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SECTION 1

INTRODUCTION

Completed landfills throughout the United States are being developed into parks, golf courses, nature areas, and other multiple-use facilities. A critical factor in achieving one of these end uses is establishing and maintaining an effective vegetative stand on the final cover soil. This manual is written for those charged with establishing such a cover. The special problems of growing plants on completed landfills are discussed, and step-by-step procedures are given for converting a closed landfill to a variety of end uses that require a vegetative cover.

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The manual has three major sections: Vegetating a completed landfill with limited funds, vegetating a completed landfill with adequate funds, and converting a hypothetical landfill to a multiple-use recreational facility with adequate funds.

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Each section presents a series of steps to be performed in sequence. Data were collected from more than 60 visits to landfills in 21 states (Flower et al., 1981 and Leone et al., 1979), other experiences in the field, textbooks, and standard references on the growth of plants under adverse conditions.

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SECTION 2

VEGETATING LANDFILLS WITH LIMITED FUNDS

STEP A-1. SELECTING AN END USE

The process of selecting an end use for a particular landfill will be largely dictated by local needs and the politcal community. The selection should take place as soon as possible to expedite initiation of all steps required to complete the project. Accomplishing each step will be much easier once a plan has been formulated. In cases where funds are limited, the plan might include a passive park, a hunting ground, or a natural open space where trees, shrubs, and grasses will be planted. (Golf courses, multiple-use parks, and other highly intensive recreational uses would require greater expenditures and will be covered in Section 2). If an end use has not been selected, then controlling erosion will be the primary short-term goal (see Step A-3).

STEP A-2. DETERMINING DEPTH OF COVER

Probably because of high costs and lack of availability, the amount and quality of soil covering the refuse in a landfill has frequently been found to be inadequate for vegetation growth. Such deficiencies need to be corrected before grass or woody vegetation is planted. The cost of covering an entire landfill with enough rich soil for satisfactory tree growth is excessive. Therefore, enough soil should be present to bring the total depth to 60 cm (not including the gas barrier layer) in all areas except where trees and shrubs will be planted; the latter areas require at least 90 cm. If portions of the landfill have no cover soil over the final refuse layer, select and spread soil according to steps B-4 and B-5.

A back-hoe is best suited for determining soil depth, because many holes can be dug in a short time. If this equipment is unavailable, a soil auger and shovel can be used. Because soil depth generally varies over the landfill, several determinations should be made at different points in the area to be planted (Fig. 1).

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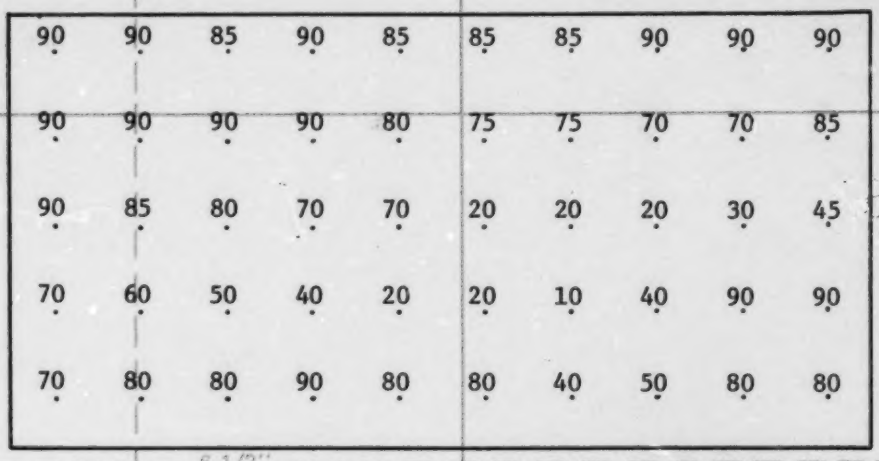

Figure 1. Suggested grid pattern for sampling soil depth on a 50-acre site (values in cm).

By digging a minimum of one hole per acre for large sites (>50 acres) and two holes per acre for smaller areas, enough data can be collected to make an adequate determination of whether additional soil is necessary, how much is needed, and where it should be placed. Follow the procedures in Steps B-4 and B-5 when selecting and spreading additional soil cover.

Fifty holes are dug in a grid-like pattern with a back-hoe, and soil depth is measured in each hole and recorded on a map of the site (Figure 1). The results show that more soil is needed in the center of the site. Two options are available to the landscaper: 1) soil can be moved from the northwest end of the fill to the center, or 2) soil can be trucked in from another site and spread in the center. Moving the soil is the obvious choice if trees are not to be planted in the northwest end and if the soil is of good quality (see Step A-4). If the soil is poor, however, and a stand of trees is desirable (e.g., as a source of food and cover for wildlife), consider bringing soil of a higher quality for the center and planting the trees there. If the cover soil on the site is suitable for tree growth in some areas (see Step A-4), supply soil in the center to a depth of 60 cm for grass establishment and plant the trees wherever there is enough soil for tree root development (i.e. 90 cm).

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STEP A-3. ESTABLISHING AN EROSION CONTROL PROGRAM

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Testing Tolerance of Ground Cover Species

The soil on recently covered landfills must be stabilized soon after spreading to prevent erosion. But the combination of soil conditions found on completed landfills is not found in other areas. Soil concentrations of CO_2 and CH_4 can be high, and O_2 can be low. The soil is frequently of poor quality, soil moisture is often limiting, compacted soil is common, soil temperatures can be high, and exposure to weather can be extreme. Furthermore, little is known about grass and ground cover adaptability to landfills, and tolerant species have not been identified. Since no research has been published on establishing grasses on landfills, a one-growing-season study should be conducted to select landfill-tolerant grasses. Such studies can be easily performed during the operation of the active portion of the landfill. About 2 acres will accommodate the following experiments.

First, select several closed areas that will remain undisturbed for at least one growing-season if the landfill is still active. If the fill is above ground, five areas will be required--one on the flattened top, and one on each of the four compass cardinal-point side-slopes of the landfill, since species growth requirements may be specific for different exposures.

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The conditions at the experimental plots must represent those expected over most of the fill area if meaningful conclusions are to be drawn. Conditions that should be considered include (1) cover soil depth, type, and compaction, (2) soil gas concentrations, (3) refuse type, depth, age, and compaction, and (4) surface aspect and slope.

Soils in the experimental plots should be tested for pH, Mg, Ca, P, K, NO_3, NH_4, conductivity, Cu, Fe, Zn, Mn, particle size distribution, bulk density, and organic matter. Four to five samples should be collected per acre. Step A-4 gives the details on collecting these samples. Soil tests should be performed by the State Agricultural Experiment Station or other certified soil testing laboratory to indicate whether amendments and/or conditioning is required for acceptable seed germination and growth. These amendments should be applied according to soil test recommendations and mixed into the top 15 cm before the plot is seeded.

Each test area should be divided into at least three blocks and each block should be planted with all the species being evaluated in 9- to-18m^2 plots delineated by string (Figure 2). This will provide three replications of every species in each area. The species should be randomly distributed within each block. Hand seeding will be necessary. Twenty or more species can be easily handled in this manner.

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4	10	16	22	20	2	8	14	6	12	18	24
5	11	17	23	21	3	9	15	7	13	19	1
6	12	18	24	22	4	10	16	8	14	20	2

Block 1 6-1/2" Block 2 Block 3

Figure 2. Experimental design plan for testing tolerance of grass species to landfill. Numbers in blocks indicate different species.

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Seed companies and the State Agricultural Experiment Station are likely to cooperate in selecting species with which to experiment. In most cases, seed varieties should be chosen to accomodate very dry sites and the cover soil conditions particular to the landfill (these should be checked by testing the soil as in Step A-4). Species selection may require more care on fills with a known end use, since aesthetics and compatability with the end use must be considered along with erosion control. A list of species that have been recommended for strip mines or other difficult-to reclaim areas are listed in Table 1.

TABLE 1. SOME GRASSES AND LEGUMES THAT SHOULD BE TESTED FOR LANDFILL ADAPTABILITY[a]

Grasses	Legumes
Kentucky 31 Festuca arandinacea	Crownvetch Coronilla varia
Perennial ryegrass Lolium perenne	Birdsfoot trefoil Lotus corniculatus
Weeping lovegrass Eragrostis curvulara	Alfalfa Medicago sativa
Millet Echinochloa spp.	Lespedeza Lespedeza spp.
Reed canary Phalaris arundinacea	Flatpea Lathyrus
Switchgrass Panicum virgatum	
Orchard grass Dactylis glomerata	

[a]Reference: Vogel, 1981

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TABLE 2. SUGGESTED HERBACEOUS SPECIES FOR EROSION CONTROL

Geographic Regions	Seeding Time	Temporary (quick cover annual) species[a] (use one with permanent mix) Name	Seeding rate (lb/acre)	Permanent (Long lived) perennial species Name	Seeding rate (lb/acre)
Northeast & North Central U.S. and Northern Appalachia	Early spring to mid-spring	Annual ryegrass Perennial ryegrass Oats Weeping lovegrass	25 50 75 10	Ky-31 Tall fescue and Birdsfoot trefoil or Crownvetch or Flatpea	75 30 50 80
	Mid-spring to mid-summer	Foxtail millet Japanese millet Weeping lovegrass	40 50 10	Ky-31 Tall fescue and Birdsfoot trefoil or Crownvetch or Flatpea	75 30 50 80
	Late summer to early fall	Rye Winter wheat Annual ryegrass	80 80 25	Ky-31 Tall fescue and Birdsfoot trefoil or Crownvetch	75 30 50
Mid and southern Appalachia, western Kentucky, Arkansas, Oklahoma	Early spring to mid-spring	Perennial ryegrass Oats Weeping lovegrass Annual ryegrass	50 75 10 25	Ky-31 Tall fescue and Korean and/or Kobe Lespedeza[c] or Crownvetch	75 50 50
	Late summer to early fall	Rye Winter wheat Annual ryegrass Perennial ryegrass Crimson	80 80 25 50 50	Ky-31 Tall fescue and Sericea lespedeza (1/2 unhulled seed)[b] or Crownvetch	75 50 50

TABLE 2. (continued)

Geographic Regions	Seeding Time	Temporary (quick cover annual) species (use one with permanent mix)		Permanent (Long lived) perennial species	
		Name	Seeding rate (lb/acre)	Name	Seeding rate (lb/acre)
Mid and Southern Appalachia	Early-spring to mid-spring	Weeping lovegrass	10	Ky-31 Tall fescue and	75
		Sorghums	80	Sericea lespedeza[b] or	50
		Pearl millet	50	Korean and/or Kobe	
		Foxtail millet	50	Lespedeza [c]	50
		Browntop millet	60		
Illinois, Indiana, Iowa, Northern Missouri	Early spring to mid-spring	Oats	75	Ky-31 Tall fescue or	75
		Annual ryegrass	25	Smooth bromegrass and	75
		Perennial ryegrass	50	Alfalfa or	50
				Birdsfoot trefoil or	30
				Crownvetch	50
Missouri, Kansas, Oklahoma	Early spring to mid-spring	Oats	75	Ky-31 Tall fescue and	75
				Alfalfa or	50
				Crownvetch	50
	Late summer to early fall	Winter wheat	120	Ky-31 Tall fescue and	75
		Rye	120	Alfalfa	50

a/ Use only one of the temporary species at rates shown. If more than one is used, reduce seeding rate of each species in proportion to number used (i.e., for two species, use half the seeding rate of each).

b/ Half or more of Sericea lespedeza seed should be unhulled and unscarified to reduce the amount of fall germination and insure sufficient seed for germination next spring.

c/ These annual lespedezas usually reseed each year and may become a permanent component of the vegetative cover.

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The experiments should be planned so that seed can be sown preferably in the fall, or where necessary, in the very early spring. The seeding rate, which varies with the species, can be suggested by the seed supplier. Seed companies and soil conservationists generally recommend that the seeding rate be several times that specified for undisturbed lands. Several legumes (Table 1) should be tested along with the grasses; since they are widely adaptable and require far less nitrogen for growth, they are often used for reclamation purposes.

Mixtures of annual and perennial species (Table 2) are reported to be best suited for stabilizing soil and protecting against erosion on reclaimed strip mines. The annual plants provide a quick temporary cover that is succeeded by a more permanent perennial species. Seeding rate recommendations should be followed carefully for the quick-cover species, because higher rates could produce dense stands that prevent or retard establishment of the permanent species.

If it becomes necessary to cover portions of the landfill with soil-holding grasses before the experiments have been completed, then the county agricultural agent or soil conservation service can supply the standard seeding and feeding rate (based on the soil analysis outlined in Step A-4) for that area for the species selected from Table 1 or otherwise recommended by the county agent.

Mixtures for spring and fall seeding are suggested in Table 2. Some of the mixtures suited for erosion control and site stabilization are not compatible with other land uses. For example, Sericea lespedeza and flatpea are excellent for long-term erosion control, but their value as forage and wildlife habitat is lower than that of other legume species. Species should thus be selected for their suitability for the approved land use as well as for their ability to control erosion. Some specifications are given in Table 3 for erosion control plantings found to be adapted to conditions on landfill sites in Pennsylvania (Swope, 1975).

TABLE 3. PREFERRED VARIETIES OF SEED FOR EROSION CONTROL ON PENNSYLVANIA LANDFILLS

Species	Variety	Lbs/Acre
Tall fescue	K-31	20
Birdsfoot trefoil	Empire	4
Crownvetch	Penngift	6

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Planting Procedures

The best procedure to prevent erosion is to microterrace steep, sloping ground before seeding and mulching. Microterracing can be accomplished by running a wide-tracked bulldozer up and down the slope without touching the soil with the blade, to create a series of ridges and troughs across the side of the slope that will help prevent erosion and aid in seed germination and growth.

The seed should be handspread in each subdivision and raked into the soil. A mulch and tack designed to hold the seed in place should be applied to sloping areas where grass seed has been planted to prevent the seed and soil from washing out during heavy rains and to help keep moisture in the soil. Some of the annuals can be seeded in the spring and then cut and used as a mulch in a fall perennial planting.

Grass and ground-cover growth should be evaluated once a month by a qualified specialist during the first 4 to 6 months following seed germination.

The soil on landfills that have been covered and completed for 1 or more years may have volunteer and planted vegetation that was placed there before plans were developed for a specific end use. If the particular use will include a natural area, consider testing those species that are already volunteering on the site. These are likely to include a variety of annual species if the site is young, or perennials if the site has been established for 2 or more years. Begin these experiments in the fall so that the following three steps (determining soil nutrients and bulk density and amending the cover soil) can be implemented during the next summer. Planting over the entire landfill can thus be done the following fall.

STEP A-4. DETERMINING THE SOIL NUTRIENT STATUS

Sampling Procedure

Before or during the grass and ground cover experiments, soil tests should be made for pH, the major nutrients (nitrogen, potassium, and phosphorus), conductivity, bulk density, and organic matter. Where possible, tests should be made for the other macro-and micro-nutrients mentioned in Step A-3. Soil samples for these tests should be collected over the entire landfill in a number of areas within the proposed planting sites. A grid or zig-zag sample pattern should be used. If the cover soil is homogeneous and originated from a single source then one sample for each 5 acres may be sufficient. But if a wide variety of materials were used as cover, then a more frequent sampling pattern should be designed. Samples should be collected from a 0 to 20-cm-deep soil column. Five subsamples should be collected over an area and pooled to form a single composite sample. Any of a number of soil auger types or shovels may be used to obtain samples (picks and shovels may be required in very compacted soils). Decaying plant material, roots, etc. should be removed from the sample.

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Fertilizer

The local county agricultural agent or soil conservation service office may help to collect and analyze the samples, interpret the results, and make recommendations for the addition of fertilizer and/or lime. Remember however, that fertilizer may encourage such rapid, vigorous growth of the herbaceous vegetation that the establishment of woody species from seed may be supressed or prevented. Again, such site-specific problems must be worked out with local officials and reclamation specialists.

Metals

Soils that contain high concentrations of zinc, copper, manganese, iron, cadmium, or lead should not be used for cover material unless this situation can be corrected by increasing the pH between 6.5 and 7.0, increasing the phosphorus content or adding organic matter. Studies are available on the relationship of the metal contents of soils to plant growth (Chaney, 1973).

Conductivity

Conductivity is an important soil characteristic that is frequently neglected in routine analysis. Since salt content can dramatically affect plant root growth and water balance, avoid planting in soils with a conductivity greater than 2 mmohs/cm. Soils with greater conductivity can be used only after rain water has leached enough salt from the soil to bring it within acceptable limits (i.e., less than 2 mmohs). This process may take several weeks or months, depending on the amount of rainfall and drainage characteristics. Salts may never leach from soils in the drier parts of the country. Conductivity tests can be performed along with the more routine analyses.

STEP A-5. DETERMINING SOIL BULK DENSITY

Cover soil is frequently compacted by landfill equipment during spreading operations to bulk densities exceeding 2.0 g/cm^3. Bulk density can be determined by weighing two or three undisturbed soil cores of a known volume (e.g., 300 cm^3) for each acre. If the density is greater than 1.7 to 1.8 g/cm^3, plant root growth will probably be severely restricted (Bohm, 1979). Compacted soil should at least be scarified, and organic matter added to enhance the physical properties.

STEP A-6. AMENDING COVER SOIL

The soil over the entire planting area should be amended with lime, fertilizer, and/or organic matter according to recommendations from the soils lab one to several weeks before anything is planted. These materials should be incorporated into the top 15 cm of soil.

STEP A-7. SELECTING LANDFILL-TOLERANT SPECIES

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From the results of the experimental plots established in Step A-3, grasses and other ground covers can be selected for planting in the soil cover spread on the entire landfill.

STEP A-8. PLANTING GRASS AND GROUND COVERS

We know of no studies that have been done to define the best planting technique for establishing grasses on landfills, but it is generally desirable to embed the seed in the soil. Mulches have been used as an alternative to embedding the seed, but this approach is less likely to be effective on adverse growing sites such as landfills. On steeper slopes, where embedding or drilling is impossible, a mulch must be used to prevent the surface soil layers from drying out and to hold the seed on the soil until it germinates and establishes a reasonable cover.

Planting Steep Slopes

Several methods exist for dispensing seed onto the cover soil. Steep slopes that are inaccessible to conventional equipment must be hydroprocessed in one operation with fertilizer, lime, seed, mulch, and enough tack to hold the mulch on the slope. Hydroseeded soil must not be compacted during spreading and must be very friable at seeding time. Seed will germinate beneath the mulch on hard, compacted soil, but the roots will not penetrate the soil surface and will succumb to drought. Although hydroseeding has been advertised as a miraculous process for vegetating slopes and other areas with adverse growing conditions, results will be disappointing unless the soil is properly prepared with the right equipment at the proper time.

Planting Flat or Gently Sloping Ground

Many methods exist for spreading fertilizer, lime, seed, and mulch on flat and gently sloping ground (hand-spreading, use of cyclone spreader, drilling, furrowing, etc.). The method chosen will be dictated by the soil type and condition, and by other factors particular to the planting areas to be determined by the contractor. To assure that the methods used are suited to the existing conditions, these factors should be carefully studied just prior to planting.

Barren Areas

Areas may exist on the landfill cover where plants will not grow because of high landfill gas concentrations. Replanting these areas will generally not eliminate this barren area problem. Wood chips or large stones can be used to prevent erosion and provide an aesthetically pleasing appearance. If gas is extracted or otherwise recovered from the landfill, the ability of the cover soil to support vegetation will be increased. Further discussion of this matter is presented in Step B-2.

If no gas is present in the areas of poor growth, the soil should be checked for the constituents listed in Step A-3 and for erosion washout. If replanting is necessary, the area may first have to be refilled, regraded, and microterraced.

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STEP A-9. DEVELOPING TREE AND SHRUB GROWTH

Efforts to develop a good cover of woody plants should begin by ascertaining that 90 cm of soil is in place in areas where trees and shrubs will be planted. Woody plants generally have a deeper root system and require better anchorage than ground cover species. Soil added to bring the original cover to a depth of 90 cm should be selected and spread according to Steps B-4 and B-5. If sufficient funds are available, a barrier (Step B-3) should be placed beneath each tree-planting area to protect the root system from harmful landfill gases.

The least expensive and most practical means for establishing trees on a completed landfill that has been closed for some time is to plant seeds or small whips of species already establishing themselves on the landfill. Some of these species may be available from the State nursery. Since recently closed portions of landfills and older landfills with very poor cover material are not likely to support many volunteer trees or shrubs, consult Step B-8, a good reference (e.g., Harlow and Harrar, 1969), and/or the county agricultural agent to determine which of the volunteer species is best suited for the area.

After the grass has been planted, a 1-or 2-year waiting period is recommended before areas are selected for planting trees and shrubs. If the grass cover with its shallow roots dies or fails to germinate because of the influx of gases from the landfill, it is nearly certain that other deeper-rooted vegetation (trees and shrubs) will not thrive at these locations.

The procedures presented so far represent the bare minimum required for establishing plants on a completed landfill. As the funds for landfill end uses increase the more sophisticated procedures described in the next section can be used for establishing grass, shrubs, and trees.

Because gas migration into the root zone will adversely affect the survival rate of grass, shrubs, and trees, active extraction of gas from the refuse layers is recommended. This procedure, while effective, is expensive. However, if the gas can be sold for its heating value, the cost of the gas-extraction system may be recovered. If this procedure is not practical, consider placing gas barriers between the refuse and tree roots to prevent gas migration. These procedures are covered in Steps B-2 and B-3.

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SECTION 3

VEGETATING LANDFILLS WITH ADEQUATE FUNDS

STEP B-1. CONSTRUCTING THE LANDFILL

Developing an end-use plan before construction or closure of the landfill will increase the likelihood that a successful vegetation program can be implemented. Factors to be considered in vegetating a former landfill include refuse age, type, depth, and compaction; location of degradable or non-degradable refuse, proportion of refuse to daily soil cover, amount and type of final soil cover, surcharging of refuse with cover material, area climate, final contouring (including maximum slope), and gas extraction.

Minimizing Gas Production

The amount of landfill gas produced during refuse decomposition is generally related to the amount of putrescible or volatile material deposited in the landfill, age and depth of landfill, water infiltration, etc. (Emcon Assoc., 1980). To minimize gas production, the ratio of nondegradable to degradable material can be increased by including greater quantities of nonputrescibles in the refuse or by increasing the ratio of daily cover to landfilled refuse.

Placing nonputrescibles (glass, plastics, metals, rubber, concrete, etc.) in specific areas to create nonbiodegradable refuse islands may allow plants to grow in areas relatively free of landfill gases and facilitate more efficient resource recovery in the future. Gases may migrate into these zones from areas containing decomposable material, but grass, shrubs, and trees should grow better above these islands.

Minimizing Surface Settlement

Surface settlement may have to be minimized in some areas so that irrigation lines can be installed and maintained to support trees and shrubs. Islands of nonputrescible refuse have minimum surface settlement and can generally support irrigation lines without the constant maintenance required in the areas containing putrescible refuse, where frequent breaks are caused by uneven settlement. Later surface settlement can also be minimized by surcharging the refuse with the soil that will be used as cover material in the future or by filling the area with shredded or baled refuse.

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Final Contouring

A critical consideration in landfill design is the slope of the final contours. A steep-sided landfill slope allows for the placement of a greater volume of refuse, but it also promotes soil erosion and hinders vegetative establishment. Evidence indicates that slopes steeper than 3:1 (horizontal:vertical) inhibit soil stabilization - an important component during the closing of a landfill. Since recommendations for maximum allowable slope are still a subject for discussion, one must practice good judgment when grading for final contours.

STEP B-2. EXTRACTING GAS

The most successful landfill-to-park conversions in the coming years will incorporate a gas extraction system in the landfill to reduce the volume of gases escaping into the final soil cover and inhibiting root growth. These systems will be compatible with gas recovery operations and may eventually pay for a portion of the park construction and maintenance requirements.

Induced Exhaust Systems

Extracting gas from within the refuse fill by an induced exhaust system, as is currently being done in several states, should aid plant growth by reducing the quantity and pressure of landfill-generated gas. The economic value of the extraction operations may end before gas generation ceases, but successful plant growth may require continuing operation of the extraction equipment. The soil in which the vegetation established itself probably had a very low gas content: any sudden increase in gas would be likely to cause severe plant stress.

Patterns of Gas Contamination

The gases of anaerobic refuse decomposition (primarily methane and carbon dioxide) can migrate from the refuse layers into the cover soil, and in some cases into property adjacent to the landfill. The latter is most likely to occur at landfills located in former sand and gravel pits, where the surrounding soil is very porous, facilitating lateral gas flow.

Gas contamination of the cover soil will not be uniform over the entire landfill site. Some areas will contain relatively high carbon dioxide (>25%) and methane (>40%) concentrations, and consequently low oxygen (<6%) contents. Other cover soil areas may be influenced very little by the underlying refuse material.

Effect of Climate on Gas Production

Site visits to some 60 completed landfills within nine major climatic regions of the United States generally revealed a high negative correlation between plant growth and concentrations of methane and/or carbon dioxide in the root atmosphere (Flower et al., 1978). Little

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variation in the magnitude of landfill gas production and consequent vegetation damage was observed among the different climatic regions, except for the arid southwest (Arizona), where concentrations of methane and carbon dioxide were found to be somewhat less than in the either other climatic regions.

Gases from Hazardous Wastes

Very little appears in the published literature about decomposition and gas generation in hazardous waste landfills. Shen (1981) states that most organic wastes will degrade biologically and chemically into gaseous components, but no data are presented to support this statement.

STEP B-3. SELECTING GAS BARRIERS

Since landfill gases may migrate into the final cover soil even with a commercial gas extraction system in operation, special precautions should be considered when planting trees and shrubs. The best planting procedure would be to cover the entire landfill with an impervious soil layer (Lutton, 1980) or synthetic membrane to keep gases from entering the final cover soil. Provision must be made to release the gases from beneath the impervious layer. This barrier will also prevent water infiltration into the underlying refuse and thereby reduce leachate generation. If such a procedure is economically unfeasible, then gas barriers should at least be installed in areas where trees and shrubs will be planted. Of course, the grass or ground cover in other areas of the fill that do not have gas barriers will be subjected to gas contamination that may cause patchy areas of poor growth.

A variety of barriers are currently available to control gas migration. A 30-to-60-cm-thick layer of impermeable clay spread over the final refuse layer and followed by an adequate amount (>60 cm) of fertile soil effectively prevents the upward migration of landfill gases into the root zone. Polyvinyl chloride (PVC), hypalon, and other types of membrane sheeting (>20-mil) also prevent gas migration (Matrecon, 1980). Special installation requirements are illustrated in Figure 3.

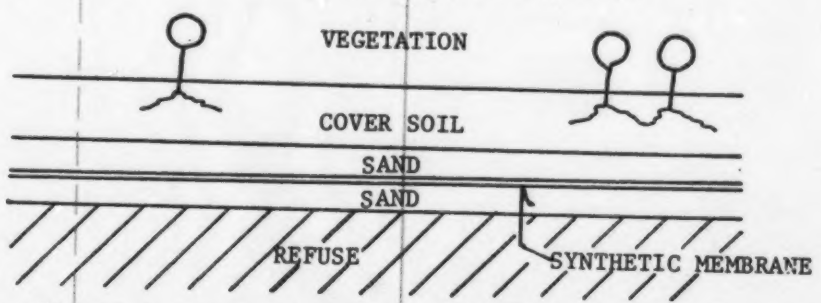

Figure 3. Gas protection scheme using synthetic membrane covering large areas over former refuse fill.

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The sand layers above and below the membranes provide physical protection during installation. Bentonite has also been effectively used to prevent gas migration into tree and grass root zones. The trees and grass pictured in Figure 4 were growing in 75 cm of soil spread over a 3-cm-thick bentonite layer that was applied by hand over a rolled 15 cm clay base. Note the poor grass growth around the mound where there was no gas barrier. At least 90 cm of soil should be spread over these barriers to insure adequate tree growth.

The trench barrier system (a modification of the mound system) may be useful if soil mounds are not desirable in a particular area. Although this system (Figure 5) has been successful on a small scale (3 x 4 m), (Leone, et al., 1979) it would be preferable to secure a barrier all the way to the soil surface and avoid leaving a portion of the cover soil exposed to the waste material and the entry of laterally migrating gases.

Another method that may be suitable for planting trees and shrubs in small areas such as planting islands in parking lots involved the construction of a saucer lined with one of the impermeable polymeric materials previously mentioned and drained by an open U-tube installed at the bottom of the saucer (Figure 6). The U-tube would allow accumulated water to drain from the bottom and prevent gases from back-flushing into the saucer.

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Proper functioning of all the gas-barrier techniques mentioned depends on the assumption that the gas barrier remains intact. Since refuse decomposition is likely to continue for scores of years, refuse settlement is also likely to continue for a similar time. Cracks or breaks in the barrier resulting from such settlement may also permit gas to migrate into previously uncontaminated areas, and areas that contain gas may become free from gas.

STEP B-4. SELECTING COVER SOIL

Many landfill operators cannot afford the luxury of selecting from a variety of final cover soils because of their high cost or lack of availability. Consequently, many revegetation attempts have failed. Methods of selecting and spreading the first layers of soil over the final refuse layers have been examined (Lutton, 1980), but the final layers of cover soil should be selected according to the criteria outlined below.

The first task in selecting cover soil is to determine what kinds of soil are available. One, two, or more types of soil may be immediately transportable to the site. The soil with a texture closest to a loam should be selected for areas where trees and shrubs will be planted, because they generally require a looser, deeper soil for root development than do the grasses and ground covers. This soil should then be tested for the constituents listed in Step A-3. Five composite samples consisting of five subsamples each (Step A-4) should be collected and sent to a certified soil testing laboratory if the soil appears to be uniform. More samples will be necessary if a variety of soils are to be used for

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Figure 4. Good tree and grass growth in 75-cm soil mound over a 3-cm thick layer of bentonite.

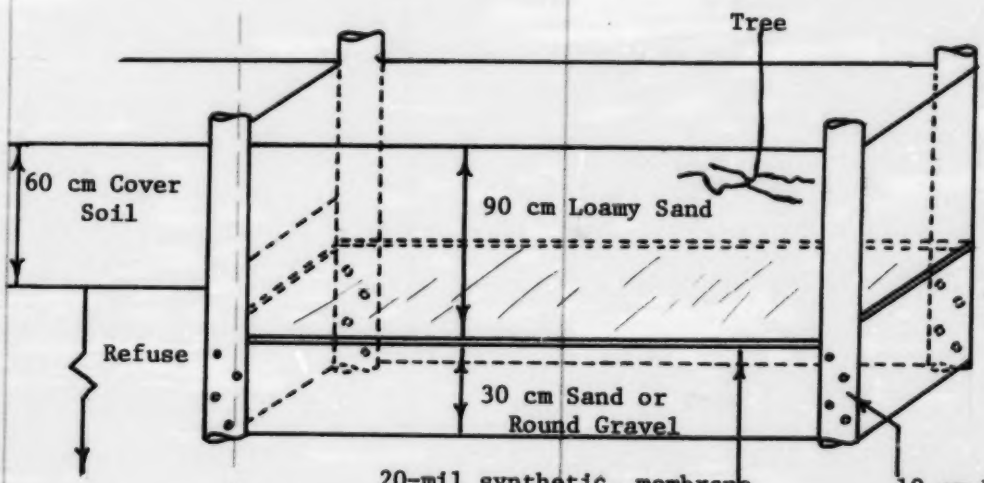

Figure 5. Gas prevention scheme for small planters. Vent pipes should be spaced no more than Z m apart.

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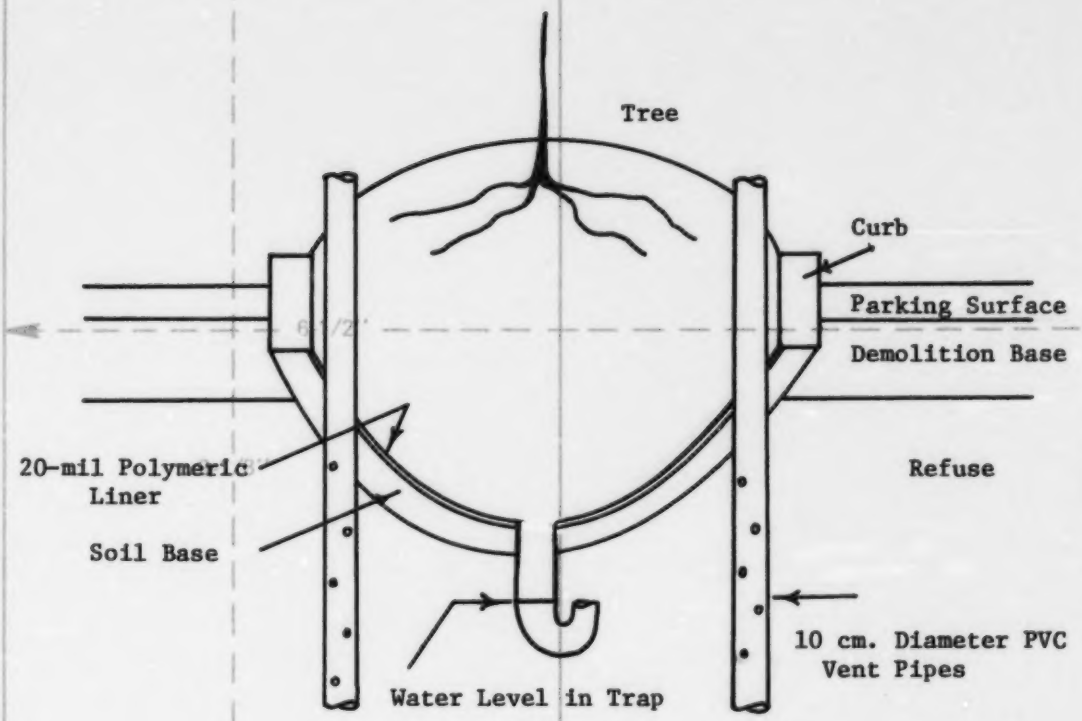

Figure 6. Gas protection scheme for vegetation planting island in a paved parking lot located over a former refuse landfill.

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cover. This decision should be made by a qualified soil scientist, because it is likely to be different for each site. The soil should be tested before it is sent to the site, because of the relative ease of amending the soil before or during spreading.

STEP B-5. SPREADING COVER SOIL.

The clay soil layers should be spread over the final refuse layers to prevent infiltration into the landfill according to recommendations in "Evaluating Cover Systems for Solid and Hazardous Waste" (Lutton, 1980). Since this soil will not adequately support vegetation, additional soil should be spread in the manner described below.

One of the most critical steps in reclamation projects is the actual placement of cover soil. Earthscrapers are usually used for this task, and the end product is a series of horizontal layers of more or less loose soil, with vertically and horizontally adjacent compacted zones. Bulk densities on the order of 2.0 g/cm^3 in the wheelings of earthscrapers are common with 1.2 g/cm^3 in the loosely spread soil between the wheels. The compacted zones have been shown to restrict root growth and downward movement of soil moisture and may contribute to surface-water ponding. Soils that compact most easily include those of clay texture, those low in organic matter (e.g., subsoils), and any soils that are wet during spreading.

The avoidance or elimination of these compacted layers can be a key to a successful reclamation project. They can be avoided by mixing organic matter with the soil before it is spread, spreading soil only when it is dry, and by using earth-moving machinery other than the normal earthscraper. Dragline excavators, bucket-wheel excavators, forward-acting shovels, and bulldozers have been proposed, but may result in considerably higher operating costs than earthscrapers (McRae, 1979).

If several different soils will be used in the final 60 to 90 cm of cover material spread over the gas/water barrier, they should be mixed together and spread as a unit, not in separate layers. Spreading soil in a thick layer will promote less over-all compaction, increased water movement, and better root growth than spreading in several thin layers.

If soil must be spread in a conventional manner and bulk densities are above 1.7 to 1.8 g/cm , consider several procedures currently available that will promote better root growth and soil water flow and ultimately provide a more successful reclamation project.

The destruction of the compacted layers by means of subsoiling or deep-tine ripping after the full thickness of soil cover has been placed will encourage better root growth, but it is not usually completely effective. The available machinery most often cannot draw the tines deeply enough or sufficiently close together; or the operation is quite often performed at the wrong soil moisture (i.e., too high) (McRae, 1979).

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Some success has been achieved with ripping each layer after it is spread and with the use of specially designed subsoiler such as a vibrating subsoiler or the double-digger. This modified equipment may be used to incorporate the organic matter into the deeper soil layers. Organic matter should preferably be mixed with the cover before it is spread.

Organic amendments are beneficial to the physical, chemical, and biological properties of most cover soil. Addition of organic materials decreases bulk density and increases water infiltration and retention. Some organic materials provide an energy source and improve the environment for beneficial soil microorganisms. These materials include humus, peat moss, manure, crop residues, food wastes, logging wastes, industrial organics, leaf compost, composted sewage sludge, or refuse compost. A soil bulk density of 1.2 to 1.4 g/cc is desirable depending on soil texture. A higher density can generally be tolerated in a coarser soil. Gypsum, perlite, or vermiculite may also be disced or chiseled into the existing soil. These materials should also be incorporated into as deep a soil layer as possible, preferably at the time the cover soil is originally spread on the landfill or on the gas/liquid barrier.

Soil structure can also be improved by establishing a grass or ground cover for several years before planting trees and shrubs. The processes of freezing and thawing, rainfall, earthworm and insect activity, percolation, and leaching will also help increase soil porosity and promote more desirable physical properties. This process of reestablishing the network of soil pores and fissures that provide adequate air exchange with the atmosphere may take many years.

STEP B-6. SOIL DEPTH

It has been reported (Bohm, 1979) that 60% to 80% of tree root volume in the forest can be found in the top 20 cm of mineral soil and that most of the fine feeder roots are in the top several centimeters. Roots are likely to be somewhat deeper in open plantings such as parks and golf courses than in the forest situation. The remaining portion of the root system is located at varying depths (from 20 to 90 cm), depending on species and soil characteristics. Thus a 30-cm soil may normally accommodate a good portion of root volume; but on a landfill, this shallow soil would dry out very quickly during seasonal drought spells and would not adequately support large trees.

Because of the excessive cost of covering the entire landfill with deep, rich soil, the planner should consider spreading 90 cm only in those areas where trees are to be planted. This layer need not be made up entirely of topsoil, but the depth at which most of the feeder roots will be growing (20 cm) should be topsoil. At least 60 cm of soil should be spread in areas where trees will not be planted. The depth of cover soil should allow enough space for grasses and other stabilizing vegetation to develop an adequate root system, provided landfill gases are not present in the cover soil.

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STEP B-7. LOCATING AREAS UNSUITED FOR TREE AND SHRUB GROWTH

Areas unsuited for tree and shrub growth can be located either before or after selecting specific sites for tree and shrub planting. Possible indicators of a potentially poor growth site include dead or no vegetation, anaerobic soil, high soil temperatures, thin cover soil, and settlement areas.

Areas with Dead or No Vegetation

The simplest method for locating unsuitable areas for trees and shrubs is to observe existing vegetation patterns. Areas where soil appears thin will most likely have very little or no plant growth (Figure 7). The CO_2 and CH_4 concentrations in these soil atmospheres are likely to be high and limiting to plant establishment. Soil temperatures are frequently elevated in these so called "hot spots", ranging anywhere from a degree or two to more than 20°C above surrounding uncontaminated soil. Such barren areas should be avoided when selecting sites for trees and shrubs.

Anaerobic Soils

Anaerobic soil conditions may not occur until after plants have been growing for some time. Vegetation will die if the soil becomes contaminated with the gases of anaerobic decomposition. If plants of different species in an area are dead, dying, or nonexistent, chances are that the soil has been contaminated with gas and that this area is poorly suited for growing plants of any kind. If plants of only one species appear to be affected, one should have a qualified plant pathologist or county agricultural agent evaluate the problem, as there may be a disease or insect problem. Some of the following tests may be performed to check for anaerobic soil conditions.

Direct Gas Measurement--

Direct measurements of combustible gases can be made in the root zone of an area where one wishes to plant. A gas sample is drawn from the soil through a hole made with a barhole-maker, to an explosimeter (the type of instrument frequently used by the utility companies when looking for leaks in their underground gas lines). Readings taken from the 30-, 60- and 90-cm depths generally present an accurate picture of the amount of gas in the cover soil. Planting is not recommended if any combustible gases are present in the cover soil. If gas is not extracted from the landfill and no clay or other barrier exists over the refuse, then portions of the soil cover will most likely become contaminated.

The carbon dioxide and oxygen contents of the root zone should also be measured. Soil gas samples can be taken from bar holes with Bacharach Fyrite or other carbon dioxide and oxygen indicators. High carbon dioxide concentrations are sometimes found in landfill soils despite the absence

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Figure 7. Area with shallow cover soil and consequently little or no plant growth.

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of combustible gases. The high carbon dioxide content is toxic to plants and indicates the possibility that soils may be anaerobic at times. In fact, current scientific evidence indicates that carbon dioxide is probably more toxic to vegetation than methane (Arthur et al., 1981). Root growth of some plant species is inhibited when soil oxygen content decreases to 10%. Other species are not adversely affected by O_2 concentrations as low as 1% (Flower et al., 1978). The high carbon dioxide and methane, and low oxygen concentrations are often highly correlated with each other.

Though an area may have been chosen for planting as a result of low combustible gas readings, differential settlement and varying gas production rates may saturate an area that was once free of landfill gases; the reverse may also occur.

Physical Characteristics--

The soil itself should be examined to detect anaerobic conditions. In many cases, unpleasant odors of anaerobic decomposition are quite noticeable in soils that are lacking in oxygen. Such soil is generally darker, damper, and more clay-like (less friable) than the soil in the aerobic condition. Aerobic soils that do not contain measurable landfill gases do not tend to accumulate as much moisture as anaerobic soils.

Tests for Ammonium-nitrogen, Manganese and Iron--

Soil tests will also generally reveal higher amounts of ammonium-nitrogen (NH_4-N) and available manganese (Mn) in anaerobic than in aerobic soils. The available iron (Fe) and zinc (Zn) content may also be considerably higher in soils that have been anaerobic for an extended period of time.

High Soil Temperatures

Temperatures in anaerobic soils are frequently higher than in nearby aerobic soil--from a degree or two to perhaps 20° or 30°C in extreme cases. The reason for these high soil temperatures is undetermined, but it may result from microbial activity, chemical reactions, and/or underground fires.

Thin Soil Cover

The amount and quality of soil covering the refuse in a landfill has frequently been found to be inadequate for vegetation growth. Measures for correcting these deficiencies are outlined in Steps A-2, A-4, A-6, B-4 and B-6.

Settled Areas

Refuse and soil settlement caused by loss of solid refuse material through biological and chemical decomposition will create an undulating surface that causes water to accumulate in low areas during periods of rain and irrigation. Trees, shrubs, and grass in flooded areas may eventually die if water remains for extended periods and/or if rainfall is frequent. Furthermore, undulating greens will not be tolerated in

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most golf courses. Operation of farm equipment may also be hindered by uneven surfaces. Provisions should therefore be made to accommodate settlement. In extremely dry climates, on the other hand, plant growth may be enhanced in the settled areas because of increased soil moisture.

STEP B-8. SELECTING TREE AND SHRUB MATERIAL

The end use for the completed landfill must be known before plant species are selected. The desired species for a nature area may be different from those selected for a park or golf course. Once an end use has been selected and the general type of vegetation has been determined, the following guidelines will be useful.

The first consideration should be the great variation in species that grow in widely separated geographic areas on this continent. Choices should be limited to plants that are known to be adaptable to the areas and that will be commercially available there.

The second consideration should be that refuse quality, quantity, age, and depth differ markedly from landfill to landfill and from one geographic area to another. For instance, a former open-burning dump may generate little landfill gas and undergo only minor settlement because it contains only small amounts of biodegradable organics. Variations in climate are also represented across North America. These factors and others interact to produce widely different environmental stresses as well as varying gas production rates and mixtures.

The third item to consider is that field data indicate that when the combustible gas and/or carbon dioxide concentrations are excessive and the soil is anaerobic, few if any tree species are able to survive.

Despite these limitations, research results have indicated that trees and shrubs grown successfully on completed landfill sites have a variety of common characteristics (Flower et al., 1981, Gilman et al., 1981).

Factors to be considered in choosing the tree species to be planted include growth rate, tree size, rooting depth, flood tolerance, mycorrhizal fungi and pathological considerations. A discussion of these factors follows.

Slow-Growing vs. Rapid-Growing Species

Evidence indicates that slow-growing trees are more tolerant to landfill conditions than rapid-growing species. The faster-growing trees generally draw more moisture from the soil and would therefore require more irrigation to maintain growth comparable with their growth on a non-landfill area. But, if comparison with non-landfill areas is not a concern, a faster-growing tree may be more desirable with its more quickly produced vegetative cover. Species classified as fast growers produce more total growth on a landfill than the slow growers if they are regularly

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irrigated during the first 3 years after planting. Table 4 lists some of the slow moderate- and rapid- growing tree species found in the United States.

TABLE 4. SOME SLOW, MODERATE AND RAPID GROWING TREE SPECIES FOUND IN THE UNITED STATES

Slow	Moderate	Rapid
Serviceberry	Littleleaf European linden	Summershade Norway maple
Sargent cherry	European white birch	Shademaster thornless honey locust
European hornbeam	October Glory red maple	Sawtooth oak
Yellow-wood	Kentucky coffee-tree	Hybrid poplar
Ginkgo	Hackberry	Willow oak
Flowering dogwood	Kwanzan Japanese flowering cherry	Tree-of-heaven
		Silver linden

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More complete lists are available in Pirone (1978) and Fowells (1965), or at the county agricultural agent's office.

Small versus Large Plant Material

Results of limited investigations indicate that trees planted when small (1 m-tall) show significantly better growth on landfills than do those of the same species planted when taller than 2 m, regardless of species. This phenomenon is related to the ability of a small tree to adapt its root system to the adverse environment in the cover soil by producing roots close to the surface (i.e., away from the high landfill gas concentrations that occur deeper in the soil). Roots of larger trees, on the other hand, start much deeper and sometimes cannot produce much growth toward the surface before being killed by landfill gases. In fact, by the time the larger tree adjusts to the landfill by attempting to produce a shallow root system, the smaller specimens, which started with a shallow root system, may actually equal or surpass the larger trees. If it is necessary to plant trees taller than 1.5 m, plant them on a raised bed to provide an adequate depth of soil uncontaminated by landfill gas to accomodate roots already developed in non-landfill soil. Larger plant material can be used only if landfill gas is kept from the root system and the plants are well irrigated.

Volunteer Species

Although volunteer tree species (early successional species) have not been specifically studied on landfills, they are generally very adaptable

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to poor soil conditions and are often the best species for establishing trees in a low public-use area of a landfill. Volunteer species indigenous to several areas of the country are given in Table 5.

TABLE 5. VOLUNTEER (PIONEER) TREE SPECIES INDIGENOUS TO VARIOUS GEOGRAPHIC AREAS OF THE UNITED STATES

Southeast	Northeast-Great Lakes
Mimosa	Jack pine
Eastern cottonwood	Quaking aspen
Sweetgum	Pin cherry
Red stemmed dogwood	Red stemmed dogwood
Loblolly pine	Paper birch
Eastern red cedar	Boxelder
Sumac	
Boxelder	**Plains States**
Northeast	Choke cherry
	Boxelder
Gray birch	Red stemmed dogwood
Mulberry	Black locust
Paulownia	
Catalpa	**Northwest**
Eastern red cedar	
Red stemmed dogwood	Red alder
Red maple	Red stemmed dogwood
Bayberry	Quaking aspen
Quaking aspen	Boxelder
Hybrid poplar	
Sumac	**Appalachia**
Boxelder	
Black locust	Black locust
	Boxelder
	Red stemmed dogwood
	Puerto Rico
	Mimosa
	Acacia
	West-Indian locust
	Hollywood
	Dominican mahogany
	Lignum vitae

Additional information on volunteer species can be found in Harlow and Harrar, 1969.

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Natural Rooting Depth

Tree and shrub species that enjoy shallow root systems were found to be significantly more adapted to landfill sites than species requiring a much deeper root system (Table 6).

TABLE 6. VERTICAL DISTRIBUTION OF TREE ROOTS IN LANDFILL AND NON-LANDFILL SOIL

Species[a]	Average Depth (cm)	
	On Landfill	Off Landfill
Japanese black pine	7	9
Norway spruce	5	4
Hybrid poplar cuttings	6	13
Honey locust	8	17
Green ash	9	15
Hybrid poplar saplings	9	13

[a]Species at top of list were more adapted to the landfill than those at the bottom (Gilman, et al, 1981).

The deeper roots are subjected to higher concentrations of landfill gases and lower concentrations of O_2. Some species can avoid this adverse gas environment by producing a shallow root system. Observations at the South Coast Botanical Garden in Palos Verdes, California (a former 87-acre landfill site) showed that shallow-rooted plants are seldom affected by landfill gases; in some cases, however, root damage has occurred in the larger trees and shrubs (Flower et al., 1978). Several texts are readily available showing the natural rooting depth of woody species (Fowells, 1965; Harlow and Harrar, 1969), however these lists are incomplete.

The fact that trees growing on landfills generally develop shallower roots than the same species growing off the landfill emphasizes the need for frequent irrigation of landfill soils planted with woody vegetation--especially if gas is not extracted from the refuse. If landfill gas is kept out of the cover soil, roots should be able to grow deeper. Species excavated for extensive root studies on landfills had a significantly larger portion of their root system in the top soil layers (Figure 8) than in the deeper layers. But, roots were much more evenly distributed depthwise on trees growing in the nearby non-landfill control area (Figure 9).

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Figure 8. Excavated green ash on landfill showing most roots in top soil layer.

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Figure 9. Excavated green ash in control area showing even distribution depthwise of root system.

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Because many roots are found growing close to the surface and since the top several centimeters of soil regularly dry out for extended periods in the temperate zone of North America, landfill soils must be irrigated more frequently than nearby non-landfill areas to ensure good vegetation growth. Also, our field studies indicate that landfill cover-soils do not maintain as high a moisture content as the same soils off the landfill. This may be due to a lack of vertical upward transport of moisture through the refuse and greater evapotranspiration on the landfill.

Lysimeter studies have shown that plant roots can penetrate into refuse zones, but these studies fail to report on the gaseous conditions in the refuse. More than likely, the refuse was not in an anaerobic state, since most plant roots soon succumb in such environments. Few roots on the one landfill studied ever grew deeper than 20 cm. Those that were deeper always died before reaching the refuse--probably from the lack of oxygen in areas close to the refuse.

It is difficult to know whether tree roots will penetrate a synthetic membrane placed over the refuse as a gas and liquid barrier. If the seal remains intact (i.e., if settlement does not disturb the integrity of the membrane), and if landfill gas is kept from the soil above the seal, then roots may penetrate 1 m of soil and grow to the membrane. Root growth may continue if water has drained away from this point. The propensity for roots to attempt to penetrate this layer would be species-dependent (i.e., the shallower rooted species are not as likely to penetrate the membrane as the more deeply rooted trees). Also a factor is the extreme force required to penetrate a 20-mil PVC membrane. Research in this area is lacking, so no definite answers exist presently. Techniques such as surface fertilizing (as opposed to fertilizing at depth, the standard procedure for tree fertilization) and frequent light irrigation will promote shallow-rootedness. Since the roots will be shallow, irrigation will be required to maintain the trees and shrubs on such an area.

The root systems of grasses are generally much shallower than tree roots, so these roots should not penetrate gas/liquid barriers if at least 60 cm of cover is present above the barrier.

Flood Tolerance

Our field data indicate that the changes produced by landfill gases in the cover soils are similar to those imposed by the flooding of soils; the difference is that the high moisture content is lacking on a landfill. Thus species that are resistant to wet feet (flooding conditions) may do well on landfills only if they are supplied with adequate water. Dry-site species should be planted if water will not be readily available.

Size of Plants at Maturity

Another factor to consider when selecting species for landfills is size of the tree at maturity. If the only cover soil available for root growth is relatively shallow (30 to 60 cm), a tree should be chosen that

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remains relatively small at maturity; otherwise there is a risk that the tree will topple during high-volocity winds. If a deeper soil cover (>1 m) is available to the roots, the risk of windthrow will be diminished because the root systems has adequate soil space to produce anchor roots (provided landfill gases are kept out of the cover soil and the trees are irrigated). A number of publications contain information on tree height at maturity (Fowells, 1965; Pirone, 1978)). The county agricultural agent, local nurseries, and landscape architects can provide information for a particular locale. Some of the smaller trees and shrubs are listed in Table 7.

TABLE 7. SOME SMALL TREES AND SHRUBS (LESS THAN 9m TALL AT MATURITY)

Common Name	Latin Name
Upright European hornbeam	Carpinus betulus f. fastigiata
Serviceberry	Amelanchier spp.
Hawthorn	Crataegus spp.
Goldentrain tree	Voelreuteria paniculata
Flowering dogwood	Cornus florida
Kwanzan cherry	Prunus serrulata 'Kwanzan'
Black chokecherry	Aronia melanocarpa
Common chokecherry	Prunus virginiana
American elder	Sambucus canadensis
Sawtooth oak	Quercus acutissima
Osage-orange	Maclura pomifera
Crabapple	Malus spp
Virginia pine	Pinus virginiana
Eastern red cedar	Juniperus virginiana

Trees that are small at maturity should be chosen if cover soils are shallow, if gas is not extracted from the fill, or if a gas barrier is not installed.

Mycorrhizal Fungi

Mycorrhizal fungi in association with plant roots have been shown to greatly increase water and nutrient uptake by the plants. This symbiotic association has been successfully used in reclamation of coal strip mines. Mycorrhizae may also aid in successfully establishing vegetation on completed dump sites, since landfill cover soil frequently has a poor capacity for holding nutrients and water. Spore- and mycelium-inoculated soil has been tested for its ability to promote mycelium development on trees in landfill cover soil (Telson, Leone, and Flower, 1980 personal communication). Results of limited experiments indicate that both forms of inoculation may be viable alternatives to

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planting trees in un-inoculated soil; however, the spore inoculum appears to be more suited to areas of higher gas content. The roots may be inoculated directly just before planting to increase the likelihood of successfully establishing the beneficial mycorrhizal relationship.

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Pathological Considerations

The selection of trees, shrubs or grasses should always be based on their ability to withstand attack by damaging diseases or insects common to the given area. The county agricultural agent or soil conservation service should be contacted, as they can frequently provide valuable practical information concerning disease and insect-resistant plant material, optimum planting time, proper fertilization, and other amendments critical to an insect and disease control program.

STEP B-9. PLANTING AND MAINTAINING VEGETATION

Trees and shrubs survive best if planted in early spring or fall. The Extension Service or Soil Conservation Service can identify which planting time is best for a specific area and species. Do not plant during the summer. Plants purchased from a nursery and delivered to the site should be planted as soon as possible. Bare-rooted material can dry out in a matter of hours if left in the sun. Balled and burlapped material can be left for some time longer, but it must be irrigated within a day or two, depending on the weather conditions. One person should not be scheduled to plant too many trees in one day. Schedule the work load so that only the trees that can be planted in a day are present on the site. In the long run, it may be more desirable to schedule a pick-up or delivery of plants each day, if practical. If all the trees must be delivered on the same day, arrangements should be made for storing the plants in a shaded, preferably cool, indoor environment free from wind. Regardless of how the plants are stored or how soon after delivery they are put into the ground, an irrigation truck or other water-supplying vehicle should be made available to deliver several gallons of water to each tree at the time of planting.

A planting hole about twice as wide as the root mass diameter and up to 15 cm deeper than the deepest root is well suited for trees and shrubs. Care should be taken to avoid compacting the sides of the planting hole; such a step might promote prolific root growth inside the original hole but inhibit root penetration into the surrounding soil.

Mix some of the original cover soil with some loamy textured material (preferably a highly organic soil) and spread enough of it in the bottom of the hole to make a 15-cm deep layer (50:50 mixture would be a desirable combination). Hold the main stem of the tree or shrub and fill in around the root system until the hole is half filled. Gently press the soil down with the sole of your shoe; do not pack it down.

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During the backfilling process, be sure to relocate the roots so that their depth is equal to their original depth in the nursery. The latter can usually be determined by letting the roots hang freely before planting. Do not compact all the roots at the bottom of the hole. Spread them out as much as possible. At this point, the soil should be watered so that the entire root system has been moistened. This step may take one to several gallons, depending on tree size. When the water has all soaked into the soil, fill the rest of the hole with the soil mix and gently press the soil down with your foot. Form a ridge around the stem with an inside diameter about equal to the extent of the root system and fill this well with water. These simple procedures will retain all possible moisture from rainfall and irrigation and help trees survive through the most critical first season. Mulching with wood chips, bark, sawdust, grass clippings, plant debris, or many other materials can help control water loss by reducing weed growth and evaporation from the soil surface around the trees.

The principles set forth above for planting small, bare-rooted trees generally hold for planting older, larger balled-and-burlapped specimens. We do not recommend planting trees older than 2 to 3 years, or taller than 1 to 1.5 m with root systems 15 cm or more below the soil surface unless specific provisions for preventing gas migration into the root zone have been implemented and the soil is at least 90 cm deep. If it is impossible to obtain small seedlings for planting, several additional provisions are necessary for the larger trees. First, more water will be required at the time of planting and during subsequent irrigation periods to saturate the soil around the root system. Second, each of the trees must be supported with at least two stakes and preferably three.

The principles of maintaining plant material on completed landfill sites are no different from those for non-landfill areas except that additional irrigation is required. Soil with a low nutrient status must be fertilized, and soils with the wrong pH (below 5.5 and above 7.0) must be limed or acidified to desirable limits. The pH and nutrient levels in the soils should be tested periodically (every 2 to 3 years) after planting. Fall is the best season for such testing so that any necessary soil application can be made in early spring. The county agricultural agent and Step A-4 can provide information on proper soil sampling methods and interpretion of the test results.

Irrigation is an extremely important requirement for establishing and maintaining healthy plant material on former sanitary landfills, particularly during the first 2 to 3 years after planting. After this time, roots may have established a large enough system to withstand moderate drought periods; however, irrigation should be practiced during extended hot, humid weather, even for large, established trees. This additional watering is needed because of the shallow roots close to the landfill soil surface where there is little available soil moisture during extended dry periods. In-ground irrigation systems require continual repair, since settlement is likely to cause frequent breaks in the pipes and thus increase maintenance costs. Various above-ground, expandable joint irrigation systems are available.

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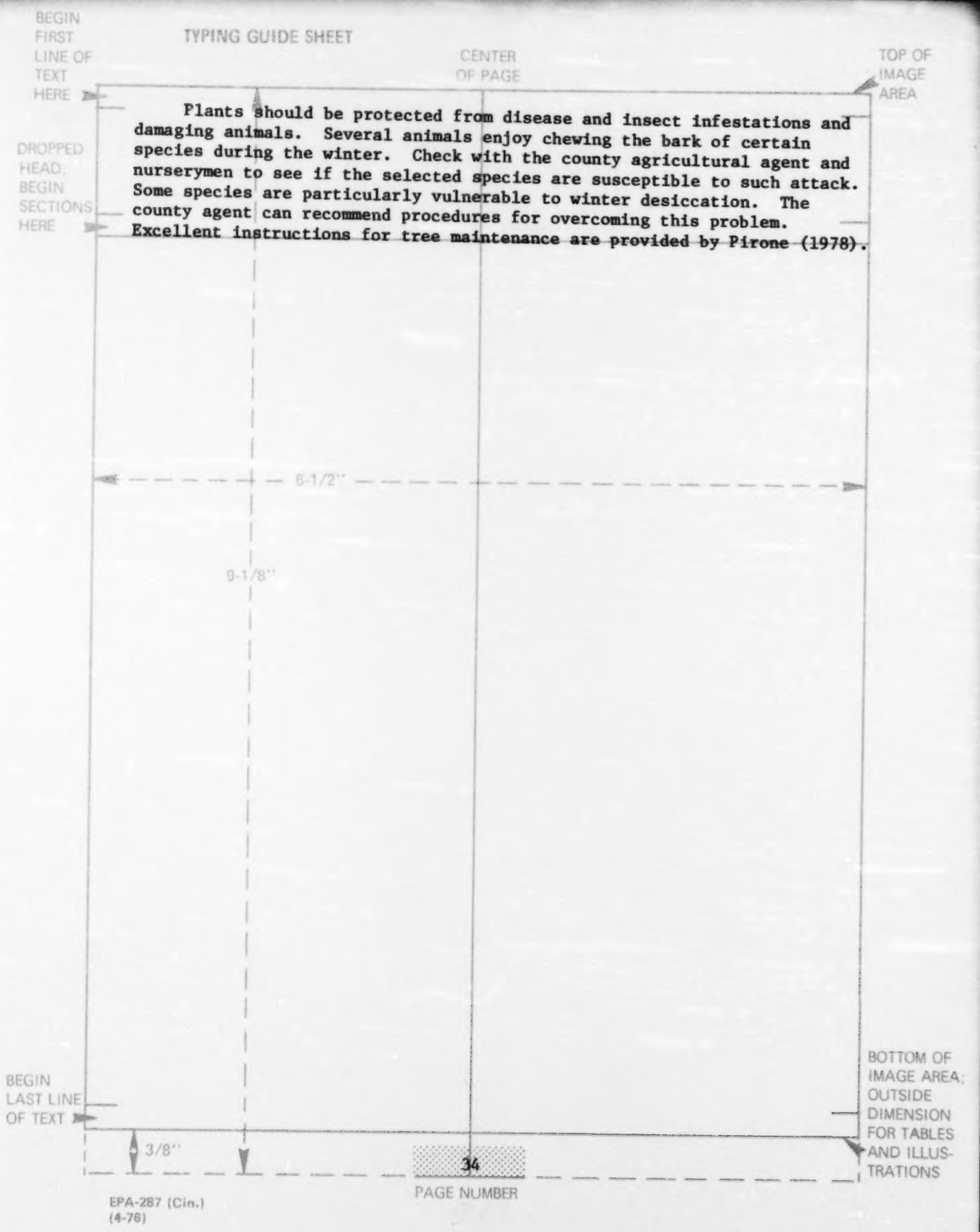
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Plants should be protected from disease and insect infestations and damaging animals. Several animals enjoy chewing the bark of certain species during the winter. Check with the county agricultural agent and nurserymen to see if the selected species are susceptible to such attack. Some species are particularly vulnerable to winter desiccation. The county agent can recommend procedures for overcoming this problem. Excellent instructions for tree maintenance are provided by Pirone (1978).
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SECTION 3

LANDFILL CONVERSION: A HYPOTHETICAL CASE

This section uses a hypothetical example to illustrate the procedures described in this manual for closing a landfill and converting it into a multiple-use recreational facility where adequate funds are available to select from a variety of cover materials, gas barriers, and tree species.

For this hypothetical landfill, a landscape architect recommends that a larger variety of end uses be incorporated into the reclamation plan, including a nine-hole golf course, botanical garden, toboggan run, picnic area, nature area, tree and shrub nursery for replacing dead plants, bicycle paths, and campgrounds.

Ideally, gases should either be extracted from within the landfill layers or the entire landfill covered by a gas barrier with passive gas vents. The following suggests methods for developing the end use where neither a complete gas extraction system or gas-barrier was instituted.

Consider the type, age, and depth of refuse when choosing areas to locate the various recreational facilities. Gas problems are likely to be somewhat less severe in the older, shallower, and least putrescible refuse areas, so they should be chosen as sites for the botanical garden and nursery. Any area receiving only demolition debris would be well suited for these uses. If putrescible materials are present (as is generally the case), install one of the gas barrier systems described in Step B-3 and spread a high -quality soil above it. If little or no putrescible material was placed here, then check for combustible gas at the 60-and 90-cm depths (see Step B-7) in 10 to 15 locations per acre, since gases can migrate from adjacent areas containing putrescibles and adversely affect vegetation. If combustible gas readings are consistently 100% of the lower explosive limit or higher in concentration, a gas barrier should definitely be installed (Step B-3) before additional soil is spread (Step B-5) or before trees and shrubs are planted (Step B-9). Cover material can be removed and stockpiled to give a total depth of 90 cm in tree-growth areas. Trees should not be planted on a landfill without a gas-barrier, since more than 50% of unshielded specimens may be killed during the first year after planting. An above-ground irrigation system should be installed so that every tree will be watered during the growing season.

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The trees on the golf course can be planted in soil mounds underlaid with a suitable gas barrier such as 20-mil PVC sheeting, a 30-cm-thick clay layer, or a 3-cm-thick layer of bentonite. This method does not protect the grass in the fairways, however. No remedy exists for this problem, and replanting will not help unless the gas later moves away from the area. The course superintendent can check for this occurrence every 1 or 2 months after the problem arises. If the problem persists, consider converting the area into a sand trap. The course architect may even consider locating the sand traps 1 or 2 years after the fairways are established so that they can all be situated over areas of gas effusion where they will serve as passive gas vents.

A system must be designed to accommodate settling beneath the greens, and perhaps the tees, since these areas must remain flat. Reinforced concrete slabs can be installed under each green so that, as the ground settles, the green will move as a single unit and remain flat. Unfortunately, it may not retain the same pitch.

The nature area can be planted with native volunteer trees, shrubs, and grasses in a fashion simulating natural succession. If barriers are not installed, the trees and shrubs should be planted as seeds or 1-year whips so that the root systems can adapt to the soil conditions. A 90-cm cover of soil should be placed over the refuse, and the soil should be checked for nutrients (Step A-4) and bulk density (Step A-5). Areas that do not support plant growth can at least be used for educational purposes. Such areas can dramatically demonstrate the effects of gas kill on vegetation.

The picnic areas, tobaggon runs, and camp grounds should be seeded with grass and perhaps other ground covers if desirable. Species should be chosen that performed best in the experimental test grounds established several years earlier (Step A-3). Bare spots where no vegetation grows because of soil gas contamination can be covered with stones or wood-chips to help control erosion and make the area presentable. Trees can be planted in groves if a gas barrier is placed 90 cm below the soil surface.

A perennial maintenance program must be instituted to keep this multiple-use facility operating effectively. Dead trees must be removed and new ones must be planted. Living trees must be fertilized, pruned, and treated for insects and diseases. Grasses must be maintained and the nursery, botanical garden, and golf course will need special attention. Erosion must be checked in bare areas that develop. The soil surface must be maintained in areas of uneven settlement throughout the park, and the plants must be irrigated more frequently than those on off-landfill parks. A reputable tree expert company, arborist, or landscaper should be retained for professional services and recommendations throughout the life of the park.

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